XXVIII. *Inveſtigation of the Cauſe of that Indiſtinctneſs of Viſion which has been aſcribed to the ſmallneſs of the* Optic *Pencil. By* William Herſchel, *LL.D. F.R.S.*

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SOON after my firſt eſſays of uſing high powers with the Newtonian teleſcope, I began to doubt whether an opinion which has been entertained by ſeveral eminent authors, "that "viſion will grow indiſtinct, when the optic pencils are leſs "than the 40th or 50th part of an inch," would hold good in all caſes. To judge according to ſo rigid a criterion, I perceived that I was not intitled to ſee diſtinctly with a power much more than about 320, in a 7-feet teleſcope which bore an aperture of 6,4 inches; whereas in many experiments on double ſtars I found myſelf very well pleaſed with magnifiers that far exceeded ſuch narrow limits. This induced me, as it were, by way of apology to myſelf, for ſeeing well where I ought to have ſeen leſs diſtinctly, to make a few experiments on the ſubject of the diameter of optic pencils. It occurred to me, that an opinion which limits them to any given ſize cannot be ſupported by theory, which does not determine on ſubjects of this nature, but muſt be decided, like many other phyſical queſtions relating to matters of fact, by careful experiments made upon the ſubject. The way, therefore, to come at truth, in a caſe which ſeemed to me of conſiderable importance, lay ſtill open to me, as it had done to former obſervers;

ſervers; and I thought myſelf authoriſed, according to a Carteſian maxim (*Dubia etiam pro falſis habenda*), to ſuppoſe, for a while, the ſize of optic pencils, requiſite for diſtinct viſion, intirely undecided.

The firſt opportunity I had of making the propoſed experiments was in the year 1778, and the reſult of them proved ſo deciſive that I have never ſince reſumed the ſubject; and had it not been for a late converſation with ſome of my highly eſteemed and learned friends, I might probably have left the papers, on which theſe experiments were recorded, among the reſt of thoſe that are laid aſide when they have afforded me the information I want. But a doubt ſeeming ſtill to be entertained on the ſubject of the ſmallneſs of the optic pencils, it may now be proper for me to communicate theſe experiments, that it may appear how far the concluſions I have drawn from them are warranted by the facts on which I ſuppoſe them to reſt.

Experiments with the naked eye.

Exp. 1. Through a very thin plate of braſs I made a minute hole with the fine point of a needle; its magnified diameter, very accurately meaſured under a double microſcope, I found to be ,465 of an inch, while under the ſame apparatus a line of ,05 in length gave a magnified image of 3,545 inches. Hence I concluded, that the real diameter of the perforation was about the 152d part of an inch. Through this ſmall opening, held cloſe to the eye, I could very diſtinctly read any printed letters on which I made the trial. Proper allowance muſt be made for the very inconvenient ſituation of the eye, which by the unuſual cloſeneſs to the paper cannot be expected to ſee with its common facility. Beſides, the continual motion of the letters, which is required on account of the ſmallneſs of the field of view, muſt needs take up a conſiderable time.

Exp. 2. In ſome other pieces of braſs I made ſmaller holes; and among many, that were meaſured with the ſame accuracy as in the former experiment, I found one whoſe magnified diameter was ,29: hence the real diameter could not exceed the 244th part of an inch. Through this opening I could alſo read the ſame letters; but the difficulty of managing ſo as not to intercept all the incident light, as well as the very uneaſy ſituation of the eye, were ſufficient reaſons for not carrying the intended experiments any further under this form. Beſides, I ſhould hardly have allowed them to be fair, if, on a further contraction of the hole in the braſs plate, an indiſtinctneſs had come on; as we might well have ſuſpected at leaſt two other cauſes, beſides the ſmallneſs of the pencils, to contribute to ſuch an imperfection; *viz.* want of light, and a deflection of it on the contracted edges of the hole.

Microſcopic Experiments.

Exp. 3. I had now recourſe to a double microſcope, conſiſting, for ſimplicity's ſake, of only two lenſes. The focal length of the eye-glaſs, carefully aſcertained by an object half a mile off, being ,9; the diſtance of the object-glaſs from the eye-glaſs 9,36; and the aperture of the object-glaſs ,0405. Hence we compute that the diameter of the optic pencil, when it entered the eye, could not exceed the 232d part of an inch; yet with this conſtruction I ſaw very diſtinctly every object I placed under the microſcope.

Exp. 4. I reduced the aperture of the object-glaſs to ,013; hence the pencil was found to be the 724th part of an inch; and yet I ſaw with this conſtruction very diſtinctly every object that was placed under the magnifier.

Exp. 5. I made a ſecond reduction of the aperture of the object-glaſs, ſo that now it was no more than ,0052; and therefore the optic pencil leſs than the 1800th part of an inch; and yet I could very well count the briſtles on the edge of the wing of a fly, and diſtinguiſh their length and thickneſs.

Exp. 6. Changing the conſtruction of the microſcope, I now reduced the pencils by an increaſe of power. Solar focus of the eye-glaſs ,52; diſtance between the object-glaſs and eye-glaſs 7,6; aperture the ſame as in the third experiment. This gave me a pencil of the 336th part of an inch, with which I ſaw very diſtinctly.

Exp. 7. Applying now the reduced aperture of the fourth experiment, I had a pencil of the 1139th part of an inch, with which I ſaw very well.

Exp. 8. I changed the eye lens for another of ,171 focal length; the object-glaſs and diſtance between the two lenſes remaining as in the two laſt experiments; aperture ,02. This gave a pencil of the 2173d part of an inch, with which I could count, or rather ſucceſſively ſee, the briſtles before-mentioned very well; the field, on account of the great power, not taking in more than two large and a ſmall one at a time.

Exp. 9. I was now convinced, that we may ſee diſtinctly with pencils incomparably leſs than the 40th or 50th part of an inch; and indeed ſo far from expecting any obſtruction to diſtinct viſion from the ſmallneſs of the pencils, it appeared to me now as if their ſize might in future be intirely left out of the account. With a view, however, of ſeeing what other cauſe might bring on that indiſtinctneſs which had been aſcribed to the ſmallneſs of the optic pencils, I continued theſe experiments with a variation in the apparatus, and uſed now an object lens of a different focal length; the aperture and other particulars being as in the 4th experiment. By this conſtruction, which gave me a pencil of the 724th part of an inch, I could ſee objects very well; but though they appeared diſtinctly, they were not ſo ſharp on the edges as one would wiſh to ſee them. This being compared with the 4th experiment, it appeared that, with equal pencils, unequal degrees of diſtinctneſs may take place; and a pretty ſtriking circumſtance, which ſerved to lead me in the following experiments, was, that the ſmalleſt power gave me the leaſt diſtinct image; notwithſtanding, from former trials, the goodneſs of the lenſes I employed could not be doubted.

Exp. 10. On an examination of circumſtances it occurred to me, as indeed I had already before ſurmiſed, that a certain proportion of aperture might be neceſſary to a given focal length of an object-lens or ſpeculum; and that a failure in this point might probably bring on that indiſtinctneſs which had been aſcribed to the ſmallneſs of the pencils. In order, therefore, to put this to a trial, I uſed now an object-lens of 1,25 focal length, with an aperture confined to ,01; the reſt of the apparatus being as in the 3d, 4th, and 5th experiments. The pencil in this caſe was about the 1000dth part of an inch; and though by a different conſtruction I had already ſeen very well with a pencil of not half that diameter, I found this to give me, as now I had reaſon to expect, a very indiſtinct picture, ſo much ſo indeed, that it could hardly be called a repreſentation of the object.

Exp. 11. Increaſing the aperture of the object-lens to ,0124, I had a pencil of the 758th part of an inch, but could ſee no better with it.

Exp. 12. Proceeding in the track now pointed out to me, I admitted an aperture of ,017, which gave a pencil of the 550th part of an inch, but could ſee not much better with it than before.

Exp. 13. On a farther increaſe of the aperture to ,0231, and a pencil of the 406th part of an inch, I ſaw a little better; but ſtill had not diſtinctneſs enough even to ſee the briſtles before-mentioned at all. Hence we may conclude, that, in ſuch conſtructions as the preſent one, the aperture of the object-glaſs muſt bear a conſiderable proportion to its focal length; ſince the 54th part (for ,0231 : 1,25 :: 1 : 54) is here not nearly ſufficient.

Exp. 14. To the ſame apparatus I applied a higher power, by an exchange of the eye-glaſs; but the indiſtinctneſs remained as before.

Exp. 15. Returning again to the former conſtruction, I admitted an aperture of about ,037; and having now a pencil of nearly the 250th part of an inch, I could but juſt perceive ſome of the large briſtles, which ſhews that even the 34th part (for ,037 : 1,25 :: 1 : 34) of the focal length is not a ſufficient aperture for object-lenſes that act under ſuch circumſtances as the preſent.

So far I have only related experiments that were made in the year 1778; and my opinion that the ſmallneſs of the optic pencils could be no objection to ſeeing well being thus ſupported by evident facts, I heſitated not, in a Paper on the Parallax of the Fixed Stars (Phil. Tranſ. vol. LXXII. p. 96.) to affirm, that we might ſee diſtinctly with pencils much ſmaller

ſmaller than the 40th or 50th part of an inch. It did not appear to be neceſſary, nor would the ſubject of that Paper permit me to enter into a detail of experiments; but having, in the courſe of my reading about that time, met with an account of ſome very ſmall globules made for microſcopic uſes, I contented myſelf with an inſtance of ſmall pencils taken from them. I ſhall, however, now proceed juſt to hint at a few inferences that may be drawn from theſe related experiments; as, upon a mature conſideration, we may find reaſon to believe they point out a cauſe of indiſtinctneſs of viſion hitherto never noticed by optical writers; and which, when properly inveſtigated, cannot but influence, and in ſome reſpects contribute to the improvement of, our theories in optics. For, admitting that every object-glaſs or ſpeculum, whoſe aperture bears leſs than a certain ratio to its focal length, will begin to give an indiſtinct picture, it will follow, that while former opticians have been endeavouring to diminiſh the aberrations ariſing from the ſpherical figure, and the different refrangibility of rays, by increaſing the focal length, they have been unaware of expoſing themſelves to the conſequences of the cauſe of indiſtinctneſs here pointed out. And till its influence ſhall be well aſcertained and brought to a proper theory, we muſt ſuſpect that ſuch tables as thoſe which are given in our beſt authors of optics, pointing out an aperture of leſs than 6 inches for a glaſs of 120 feet focal length (or a ratio of 1 to 240) muſt be far from having that degree of perfection which may yet be obtained. No wonder that teleſcopes, made according to theories or tables, where one of the cauſes of indiſtinctneſs is unſuſpected, and therefore left out of the account, can bear no ſmaller pencil than the 40th or 50th part of an inch! If then, on one hand, by increaſing our apertures we certainly run into great imperfections, we ought nevertheleſs alſo to conſider what dangers, on the other, we may incur by leſſening them too much.

As ſoon as convenient, I intend experimentally to purſue this ſubject, in order to obtain proper *data* for ſubmitting this cauſe of optical imperfection to theory; at preſent my engagement with the work of a 40-feet reflector will hardly permit ſo much leiſure; and till I ſhall have repeated, extended, and varied theſe experimental inveſtigations, I would wiſh them to be looked upon as mere hints that may afford matter for future diſquiſitions to the theoretical optician.